THE RELATION OF FATIGUE TO INDUSTRIAL ACCIDENTS—*Continued*

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III. RELATED INDUSTRIAL CAUSES OF ACCIDENTS

After a study of the related subjective processes accompanying work had been made and after the formula given at the close of section II had been determined upon, the writer supplemented a previous limited experience by spending considerable time in visiting factories and shops in and about Chicago. The purpose was to test the conclusions already in mind and to observe more accurately the *conditions which precede accidents.* Eleven factories and shops were visited, representing as many forms of industry.[1] Permission was obtained to wander leisurely about and thus unnoticed to observe operatives of dangerous machines while at work. About twenty types of dangerous machines were found.[2] Three accidents were directly witnessed—two at soldering machines and one at a press and drill.

As a result of these observations it appears to the writer that the chief industrial conditions leading up to and culminating in accidents are those *of monotony and speed and of unrelaxed tension,* kept up *for long hours.* This process seems to result *in increasing numbers and extent of muscular inaccuracies,* which in turn appear to be *the phenomena immediately preceding accidents.* This view in more or less detail will be supported in this section.

Proof is hardly necessary to show that monotony and great speed characterize the conditions under which operatives of dangerous machines work. In most industries, labor is so subdivided that each worker has but one small part to do. This

[1] These included the packing, canning, and steel industries; leather-goods and knitting establishments; steel-castings and box factories; various wood-working and metal-working concerns, and wagon shops.

[2] Among these types are those represented by the press and drill, the press and die, revolving knives, saws, stamping and cutting machines of various forms, and soldering machines.

part is repeated thousands of times daily. To make a small sickle section, for example, requires thirty operations by as many men and boys. Certain parts of this process make vivid the factors of monotony and speed.

A man feeds metal sheets into a machine that cuts them out in a three-cornered form, 20,000 per day . . . . one motion is required for each sheet. The two holes of the sickle section, when punched, are slightly enlarged on one side to receive the head of the rivet, 7,000 per day. Along one side of the room in which the edges of the sickle section are beveled are arranged a row of grindstones six feet across. In front of these whirring stones sit a line of powerful, heavy-faced men, not a spark of animation in their faces. They are each doing the same thing; they drop one of these plates into the slot of the frame, shove the frame against the rapidly revolving stone and then draw it back; drop, shove, draw back . . . . 5,000 times each day. In the room where the sections are serrated, a row of young men stand, feeding machines which run at great speed and with deadening noise. These machines cut the teeth on the bevel edge of the plate, 7,000 plates a day.

These monotonous, speeded-up operations in connection with dangerous machinery are found in "the manufacture of nearly every article of use or comfort with which our lives are surrounded; in the manufacture of that piano, the chair you are sitting on, the watch in your pocket, the car you ride in, the sewing machine, the meat you ate for your breakfast this morning."

In the canning factories of Pittsburgh, for instance, where tops for cans are cut from sheets of tin, the foot-press operator puts the sheets in the press, gauges it so that it will fall evenly, gives a quick pressure of the foot in order to clip the tin for each top. This quick pressure and accompanying hand movements are repeated "forty times a minute, 24,000 times a day."[3] Ernst Abbe points out that

with this sameness ("Gleichförmigkeit") and continually recurring monotony ("Einförmigkeit"), we also get the continuous ("fortgesetzte") fatigue of the same organ, of the same nerve centers, and of the same part of the brain . . . . because all that is to be done, whether muscular or mental work, must be constantly repeated ("sich wiederholen") in the same manner from morning to night, day by day, and week by week.[4]

Today, the necessary rapidity of monotonous motions fatigues workers and causes accidents. Dr. Thomas Oliver regrets

[3] Eliz. B. Butler, *Women and the Trades* (Charities Pub. Com., 1909), 36.

[4] E. Abbe, *Gesammelte Abhandlungen* (Jena, 1906), III, 225.

the attempt to americanize shipbuilding in England for the reason that this "rushing" is a cause of serious accidents.[5] Professor G. Pieraccini and Dr. R. Maffei, Florence, state that piecework, which necessitates higher speed, tends, both in itself and together with the fatigue that ensues, to favor the occurrence of labor accidents.[6] It is no exaggeration to say that the pace kills and injures more people than labor *per se*. To the extent that *the stupefying effects of monotony* and *the confusion attendant upon "speeding up"* are added to the regular development of the fatigue process, *loss of muscular control and danger of accident are increased.*

A characteristic phase of monotony and speed is unrelaxed tension of the worker. Arlidge says that the fatigue of machine operatives is more the fatigue of watching than that of working.[7] From a psychological standpoint, it is impossible to attend to very many things at a time or to attend to one thing for very long at a time. It is especially fatiguing to keep the attention on a simple process which presents no new phase, but which is a continuous repetition of a few simple movements hour by hour. It is true, of course, that these movements tend to become automatic; but when they must be made in close proximity to dangerous and rapidly revolving tools, a certain degree of voluntary attention must be exercised, or else injury will result during a moment of inattention.

Professor Henderson states that the speed of saws, for instance, is a significant factor in increasing danger, "because the swift movement increases the strain upon attention and so rapidly exhausts nervous energy."[8] The relaxation of tension which sometimes results in serious injury, says Elizabeth B. Butler, may be accounted for by the hurry of the worker who is usually ambitious, or by the weariness toward the end of the five hours' continuous work.[9]

Operatives of machinery become accustomed to the presence

[5] T. Oliver, *Diseases of Occupation* (London, 1908), 3.

[6] See Brandeis and Goldmark, *Ten-Hour Law for Women*, 75.

[7] J. T. Arlidge, *The Hygiene, Diseases and the Mortality of Occupations* (London, 1892).

[8] C. R. Henderson, "Wood-workers and Their Dangers," *World To-Day*, XIX, 975.

[9] Eliz. B. Butler, *op. cit.*, 225.

of danger and hence less on their guard against the effects of fatigue on attention. Cadbury says that workers accustomed to danger are apt to look away to talk to their companions and in a moment of relaxed tension the hand is caught under the machine.

> The incessant noise of the machinery, the excessive monotony of the work, and above all, the long hours, which are too often spent in an ill-lighted and ill-ventilated atmosphere—all tend to produce a depressing and deadening effect which cannot fail to destroy the alertness of attention.[10]

In the steel mills, for example, an alert mind is the first requirement for safety.[11] There, as elsewhere in connection with dangerous work, attention is focused more on the proper accomplishment of the work than on self-protection. But attention to the matter of self-protection in steel mills is comparable to an attempt to dodge bullets on the battlefield. Neither a steel-worker nor a soldier of that type can long retain the respect of his fellows. Attention to self-protection is bound to be secondary and incidental; but to insure the workman's safety it must be constant and keen. However instinctive this vigilance may be, it cannot be considered unfailing. The speed and intensity of the work, the heat and noise of the steel mill, the weariness of the workers, "all these things tend to numb the faculties most needed for protection."[12]

As a result of continuous and unrelaxed tension, the fatigue processes go on insidiously. The onset of fatigue is often unperceived. The tension in modern industry calls out the volitional power which urges on a fatigued worker, intensifies application, and minimizes the sensation of effort, thus concealing fatigue. Kirkpatrick emphasizes the fact that a person often does not feel weary after his power to act has been very much decreased.[13] The distinction which must be made between the sensations which supervene during the performance of the work and the lowered capacity for work as shown objectively by diminution in the amount of work executed is well

[10] Edw. Cadbury and others, *Women's Work and Wages* (University of Chicago Press, 1907), 53.

[11] Crystal Eastman, *Work-Accidents and the Law* (Charities Pub. Com., 1910), 91.

[12] *Ibid.*

[13] E. A. Kirkpatrick, *Fundamentals of Child-Study* (Macmillan, 1909), 322.

known. Rivers says that there may be complete absence of any sensations of fatigue, when the objective record shows that the work is falling off in quantity, or in quality, or in both.[14] The curve of organic fatigue follows a different outline than that which represents the production of voluntary work.[15]

Workmen are generally ignorant of the difference between the subjective development of fatigue, and its objective correlates. Unrelaxed tension in modern industry makes continuous and terrible demands on the human volitions. These, in turn, so intensify application and minimize warnings of overfatigue that the worker in the dangerous trades may suddenly through inaccurate movements find himself handicapped for life, or the wife and children may receive the unexpected message that their breadwinner has given up his life while serving at the post of duty.

The terrific mental strain due to monotony and speeding up is doubly vicious because of the fact of *long hours*. After a certain period of time, varying in length with different individuals, unrelaxed tension cannot be consistently maintained, uncertainty of movements increases, and danger of accidents multiplies. After making a careful investigation of work-hours, the National Conservation Commission says: "The present working day from a physiological standpoint is *too long,* and keeps the majority of men and women in a continual state of overfatigue.[16] . . . . The manual worker through fatigue caused by long hours is *in a continual state of overexertion.*"[17]

The situation is especially grave when the men and women kept in a continual state of overfatigue because of long hours are operatives of dangerous machinery. Further, in many industries where danger exists, the long hours of regular employment are supplemented by demands for "overtime" work during certain parts of the year. In Pittsburgh, for example, Elizabeth Butler found that many canning factories work every night until ten o'clock during the busy season, making a working week

[14] W. H. Rivers, *The Influence of Alcohol, etc., on Fatigue* (London, 1908), 2.

[15] T. Oliver, *Dangerous Trades* (London, 1902), 117.

[16] Senate Document No. 419, 61st Cong., 2d sess. (1910), 626.

[17] *Ibid.*, 666.

of over 72 hours.[18] One manager admitted that the girls under his direction "worked 75 hours a week for two months every year." He added that the factory inspectors generally did not interfere; that they usually come around in September and after the holidays, and "they never see any overtime."[19] In another factory where foot-press work was the chief type of labor, Miss Butler found that the employees are sometimes forced to work twelve and fourteen hours and "accidents are so frequent that the place has been characterized as a butcher shop."[20] As another more or less typical illustration, a "hinge factory" may be mentioned where "overtime" work until half-past eight is demanded almost throughout the year, there being no regular alternation of busy and slack seasons, but change according to orders.[21] This irregularity is peculiarly true of the laundries, where in the latter part of the week "overtime" often lasts till eleven o'clock at night and later.[22]

In regard to railway employees, Crystal Eastman quotes a yard-master as follows:

> Yardmen now usually work twelve hours, but when the yards are pressed, they often work the brakemen the sixteen-hour limit. And when a man works sixteen hours at a stretch, it often means that he has been awake eighteen or twenty hours, because there is a rule that a man must be called two and a half hours before he goes on duty.[23]

In the steel industry, the working day is usually twelve hours. A typical steel-worker says:

> I've been twenty years at the furnaces and have been working a twelve-hour day all that time, seven days in the week. . . . . We work that way for two weeks and then we work the long turn and change to the night shift. The long run is when we go on at seven Sunday morning and work through the whole twenty-four hours up to Monday morning.[24]

John A. Fitch says that in 1907 he could find only about 120 eight-hour men among the 17,000 employees in the three largest plants of the Carnegie Steel Company in Allegheny County—a

[18] Eliz. B. Butler, *op. cit.*, 39, 40.

[19] *Ibid.*, 53. [20] *Ibid.*, 233. [21] *Ibid.*, 225.

[22] See Clark and Wyatt, "Women Laundry Workers in New York," *McClure's*, XXXVI, 401–13.

[23] Crystal Eastman, *op. cit.*, 33.

[24] John A. Fitch, *The Steel-Workers* (Charities Pub. Com., 1911), 170.

trifle less than three-fourths of 1 per cent; "the prevailing work-day is twelve hours for steel-workers." But the machinists being also repair men are sometimes obliged to work much longer, occasionally "a continuous twenty-four-hour period, while sometimes the men work thirty-four hours or longer without rest."[25]

Under normal conditions, fatigue would be overcome by adequate periods of rest, but in modern industry the workman is often denied the satisfaction of the physiological demands of fatigue. The human organism is so constructed that on rare occasions great reserve powers can be called out. Modern industrial labor is such that the reserve forces are called out daily. Mental strain and muscular fatigue are phases of the general fatigue process which develops with *accumulative force,* not only in the course of a day-period, but week by week. Joteyko says that it appears certain that fatigue accumulates "s'accumule progressivement" in the organism.[26] "Fatigue is viciously progressive," says Dr. Favill.[27] The actual structural changes, the impairment of the nutritive processes, the accumulation of poisonous products when taken together make up "an overwhelming incubus which no organism can long survive."[28]

Fatigue sometimes starts a vicious circle which leads to the craving of and indulgence in means for deadening fatigue. Liquor may drive away temporarily the fatigue sensations, but in the end it will leave the workman weaker, more subject to trembling, to uncertain muscular control, and to injury.

Where fatigue is not balanced by adequate rest and nourishment, a deficit remains which is added to daily, which accumulates little by little; and the workman suffers increased susceptibility to accident. When the workman's strength becomes debilitated through overwork, he becomes incapable of attention,[29] and defenseless against accident.

Present-day operation of dangerous machinery finally resolves itself into a competition of sensitive human nerves and

[25] *Ibid.*, 174.

[26] J. Joteyko, "Participation des centres nerveux dans les phénomenes de fatigue musculaire," *L'annêe Psych.* VII, 166.

[27] H. B. Favill, "The Toxin of Fatigue," *Survey* XXIV, 772.

[28] *Ibid.*

[29] Th. Ribot, "The Psychology of Attention," *Open Court* (1896), 99.

muscles against relentless and insensitive iron.[30] The greater the number of hours that machinery must be operated per day, the feebler and more uncertain become the human forces that guide it. To the machine, time is nothing; to the working man and woman, each hour that passes beyond a certain limit *offers increasing opportunity of injury and possibility of death.*

While monotony, speed, unrelaxed tension, together with long hours, appear to be the leading general causes of industrial fatigue and hence of many accidents, it is proposed next to determine if possible the *modus operandi* of these general causes in bringing about accidents. In other words, what are the concrete, immediate conditions preceding accidents?

The writer has had access to the accident records of the state of Illinois for the year 1910.[31] These records refer to accidents which necessitated that the injured lay off from work fifteen days or over, and they apply to the various manufacturing industries, the steel industry, and to many small plants and factories in Illinois. Of the total number of accident reports—some over 3,000—which were examined, 2,678 applied to non-fatal cases and gave a fairly accurate description of what happened preceding the given accidents. The remaining 400-odd reports either omitted a description of the immediate cause or else gave it so inaccurately as to throw doubt on its value for this analysis.

The accident descriptions which apparently are accurate fall into two general classes. Class A includes the accidents where the immediate cause was evidently beyond the control of the injured—due to the breaking of machinery, to bursting of boilers, to chips of steel flying in the air. Typical statements illustrating this general class of accidents, as taken from the accident reports, are subjoined:

Scaffold collapsed.
Bolster flew out from under steam hammer.
Chip in eye.
Gas exploded.
Hot steam blew in eye.

[30] T. Oliver, *Dangerous Trades*, 117.

[31] I wish to acknowledge the courtesies shown me by Edgar T. Davies and his assistants in the office of State Factory Inspection (Chicago).

Flying nail struck eye.
Struck in the face by piece of iron . . . . due to pulley breaking.
Hot scale blew into eye.

It is beyond doubt that in the cases represented by Class A, perfect subjective control preceding the given accidents would not have made escape possible.

Class B represents those accidents in which loss of control, varying from failure to make fine co-ordinations on to gross and bungling co-ordinations and to absence of movements which might have prevented injury, appears to have been a factor. Class B is illustrated by the following typical descriptions:

Did not get her hand away soon enough and thumb was caught between billets.

Placed his finger too close to the cutter in putting in a piece of work.

Got his fingers under the die when it came down.

Caught hand under punch.

In some manner he got the small finger of right hand against the saw while the same was in motion.

Did not get his hand out of the way in time and his fingers were caught between plunger and edge of socket.

His hand slipped over the guard and caught in the knife.

His fingers went under the die when he accidentally tripped the press.

Caught his fingers in the die.

The injured accidentally placed his finger too close to the cutter in putting in a piece of work.

Automatically placed foot on treadle when tips of fingers were under die.

Hand slipped on to rip-saw.

Caught hands in knives.

Caught fingers between press and die.

Caught fingers between head of die and material.

Caught fingers in jointer while operating same.

Caught thumb between sheet metal and die.

Her finger slipped into the gear of her machine.

Of the 2,678 accident records which gave a fairly good description of what occurred immediately preceding the accidents, twelve records were of doubtful analysis. Four hundred and sixty-three cases or 17.2 per cent belonged to Class B. Of the fatal-accident reports studied the number is too small to be of much value. Twenty fatal accidents or 37.8 per cent were of Class A; and forty-one or 62.1 per cent belonged to Class B.

Table I shows that a large percentage of non-fatal accidents is immediately preceded by muscular inaccuracies. In all cases of Class B, it is conceivable that if the injured had had perfect and ready control over muscular movements he would not have suffered accident.

TABLE I

INDUSTRIAL ACCIDENTS CLASSIFIED

Year 1910	Doubtful	Class A	Class B	Total
Number	12	463	2,203	2,678
Percentage	0.4	17.2	82.2	100

In Section II it has been shown that the developing subjective fatigue processes inevitably result in increasing muscular inaccuracy; in the preceding paragraphs of this section it has been further shown that monotony, speed, mental strain in connection with long hours hasten the fatigue processes and hence greatly increase the loss of muscular control. In this section it is maintained that to the extent that fatigue is a primary cause of muscular inaccuracies, 82.2 per cent of the 2,678 accidents studied *involved fatigue as a causal factor.*

This proposition is illuminated by the fact that "the swift machinery of modern industry requires the attendants to push and guide the material in close proximity to merciless cutting tools."[32] In Chicago the writer found twenty types of machines in connection with which the operatives were working so close to revolving saws, knives, drills, rollers, or at machines of the press and die type that the misplacement of the hand a fraction of an inch meant mutilation. The three accidents which the writer witnessed were exactly of this nature—two at soldering machines and one at a press and drill—in each case a hand was misplaced a fraction of an inch and came into contact with dangerous parts of the respective machines.

At mangles, too, the danger is grave. What the girls call "millionaire work"—work that has to come out straight—in contrast with "boarding-house" work, must be shoved up to *within a quarter of an inch of the cylinder.* Fingers once caught in such mangles are crushed. Consider

[32] C. R. Henderson, *op. cit., World To-Day,* XIX, 972.

in connection with these two points the high rate of speed at which the girls feed the work into the machine, and the precarious character of their work will be realized.[33]

From these facts it is evident that the slight slips and mistakes which every person makes are exactly the phenomena which precede many serious accidents when they occur in dangerous occupations. "When a cook drops a cup, the loss is a few cents; when a structural iron-worker is guilty *of no greater inattention,* he may lose his life."[34]

The thesis of this section has been confirmed by a report prepared by the Bureau of Labor which is not off the press at this writing (April 1, 1911). The following excerpt is taken from proof sheets:

It (the fatigue process) gradually upsets those nice adjustments of the living organism upon which depend efficient labor and the safety of the worker. The margin of safety in modern industry is small. It is measured too frequently by *fractions of an inch. Reduce the alertness and the exactness with which the body responds to the necessities of its labor, and by just so much have you increased the liability that the hand will be misplaced that fraction which means mutilation.*[35]

Thus slight deviations entail serious consequences and result in industrial accidents. "The exhausted workman no longer has full control over his muscles. His results are less exact, danger by accident increases."[36] Even the skilled laborer does not work as regularly as the machine. His ability to make accurate movements shows regularly returning shrinkings as a result of the activity of the neural-muscular factors.[37] This phase of the fatigue problem has been summed up by Felix Arnold:

Concentrated activity, especially when it involves motor control, usually results in fatigue. There arises . . . . increased slowness of response. Efficiency of attention begins to decline. . . . . In simple reactions, the reaction time becomes longer. Objects in the field of attention persist for a less time in the center of control. On the subjective side, fatigue is felt as weariness, disinclination to persistent effort, sensation of strain in the muscles, lack of interest in situations which normally are of an impelling nature, and some-

[33] Clark and Wyatt, *McClure's*, XXXVI, 402.

[34] Bureau of Labor and Industrial Statistics (Wisconsin), *13th Bien. Report*, Part I, p. 4.

[35] Senate Document No. 645, v. 11, p. 42.

[36] H. Herkner, *Handwörterb. d. Staatswissensch.* (Jena, 1909), I, 1215.

[37] E. Roth, *14. Intern. Kong. f. Hyg. u. Demog.*, II, 611.

times as pain in the parts of the body affected. On the objective side fatigue is manifested by a general slackness and listlessness of the body posture, by relaxed fingers, and by asymmetrical and fidgety movements. Co-ordinations *become more bungling, incorrect, and for finer control often impossible.*[38]

If men and women subject to industrial overstrain are working at or near rapidly revolving knives or saws, are operating punches, presses, or drills at a furious rate of speed, their chances are good of being counted among the annual list (in the United States) of 30,000 killed and 500,000 injured in industry.[39]

The law of fatigue as related to accidents and given at the close of Section II may be restated in the light of the facts of this section as follows: *The irregularly increasing muscular inaccuracy which accompanies work results in correlatively increasing chances of accident.*

It is proposed to test this law by further facts. In the following section it will be attempted to verify further, if possible, the causal relationship existing between fatigue, decreasing muscular control, and accidents, by means of several series of controlled experiments in which various industrial conditions are more or less closely simulated.

IV. SOME CONTROLLED EXPERIMENTS

(From the Psychological Laboratory of the University of Chicago)[1]

Section II set forth the fact that continued work is accompanied by increasing muscular inaccuracy. In Section III it was shown that these muscular inaccuracies are the immediate phenomena preceding a large proportion of accidents. In order to determine more exactly the nature of the muscular inaccuracies which increasingly accompany continued work and

[38] Felix Arnold, *Attention and Interest* (Macmillan, 1910), 153.

[39] J. B. Andrews, "A Clinic for Industrial Diseases," *Survey*, XXV, 269.

[1] Preliminary to these experiments, the writer conducted two series of experiments on the typewriter. The striking of a typewriter key requires a definite muscular co-ordination. All variations of one-half inch and over from the correct muscle movement appear as errors on the typewritten pages. These faulty co-ordinations are similar in general nature to the muscular inaccuracies which precede many industrial accidents. The results of the typewriter experiments indicated clearly an irregular but marked increase in the number of muscular errors occurring during a given work-period. This increasing inaccuracy was accompanied by symptoms of increasing fatigue. But it will be observed that in experiments on the typewriter, the power which runs the typewriter is intrinsic; that is, the subject or operator by his own volition must keep the typewriter in motion. It appeared that these experiments would have

which result in increasing danger of accident, a type of machine for experimental purposes was designed which in its operation would combine the factors most common to industrial conditions, namely, monotony, speed, mental strain—and which at the same time would permit a computation of the muscular inaccuracies resulting from operating it.[2]

Figs. 1 and 2 will give an idea of the apparatus used. The part of the machine designated *x* in Fig. 1 appears in enlarged form in Fig. 2. The letters *a, b, c, d* represent thin brass plates so set in the top of the table that their inner lines form a square of one-inch dimensions. They do not come in contact with each other; their upper surfaces are practically on a level with the upper surface of the table. The letters *a′, b′, c′, d′* designate another set of brass strips whose inner lines are three-sixteenths of an inch from the inner lines of *a, b, c, d,* respectively. The subject was given wooden inch cubes, one side of each being covered with a thin brass plate. If the block was accurately placed its outer edges—brass side down—would exactly coincide with the inner lines of *a, b, c, d.* However, the outer edges of the brass base could extend over the lines of *a, b, c, d* practically three-sixteenths of an inch in any direction and the placement would still be counted as accurate. But the brass strips were so electrically wired that *a* and *a′, b* and *b′*, etc., represented the termini of respective circuits. Hence if the brass base of a block for instance, was misplaced to the extent that one of its sides extended over *a′,* as represented by the dotted line *r,* an electrical circuit was established and an error was recorded on an endless sheet of smoked paper carried by two slowly revolving Scripture drums, arranged after the manner of Yoakum.[3] If the block

greater value if conducted on a machine which was run by external power, e.g., by an electric motor. In this case the operator would be required to keep up with the pace set by the machine, and not set his own pace.

It was this problem which I took to Professor James R. Angell, to whom I am indebted for making possible the experiments described in this section, for designing a considerable portion of the apparatus, and for many stimulating suggestions. The apparatus which is described in the following pages was built only after a special study had been made of dangerous machines in industry. It was designed especially to incorporate as many as possible of the general features of the machines used in the dangerous trades.

[2] For the purposes of this chapter, these experiments have been presented from a sociological point of view. Much material is at hand for a psychological discussion.

[3] C. S. Yoakum, *An Experimental Study of Fatigue*, 54.

was misplaced as represented by the dotted line *r'*, the circuits represented by the termini *b* and *b'*, and *d* and *d'* were closed respectively and two errors were recorded on the smoked paper

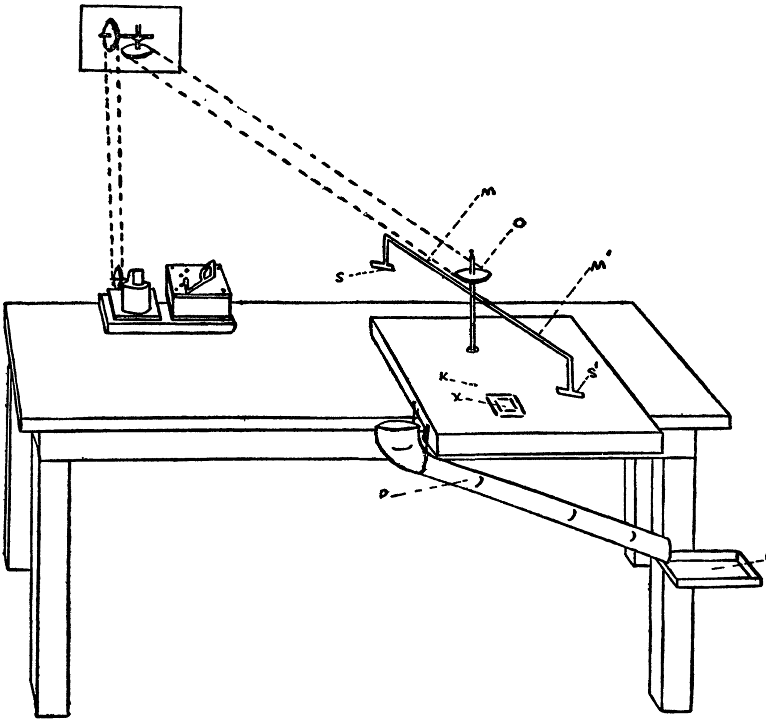

FIG. 1

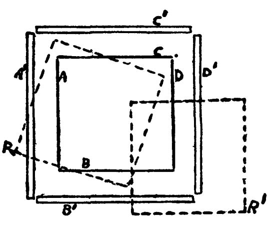

FIG. 2

by corresponding markers. It was not possible to close more than two circuits and hence make more than two errors by a single misplacement. It will be noted that the inner lines of *a'*

and d', and of b' and c' are separated by one and three-eighths inches, respectively, so that a leeway of three-eighths of an inch in either direction was given.

A revolving pulley O (Fig. 1), driven by power obtained through a speed-reducer from a motor, carried a double arm, m and m'. Both m and m' carried shields s and s', respectively, set at an angle such that when the pulley revolved, the blocks being set on the square would be brushed off to the left and toward the subject who was seated facing x. Each of the shields s and s' were of brass (as were the arms m and m' and the pulley) and each carried a small brush of fine brass wire attached to the lower inner corner. As the shield brushed off a block at x the small wire brush passed over a brass knob k and closed an electrical circuit, which occurrence was recorded by a fifth marker on the smoked paper mentioned in the preceding paragraph. Reference to the smoked paper showed the nature of errors, i.e., the direction in which the misplacement occurred, the number of errors, and their occurrence in relation to the time-element. An observation method was devised which served as a check on the record carried by the smoked paper. Because of a great variety of phenomena which happened in connection with the placement of the blocks and which the registering apparatus could not be made to record, the observation method proved more accurate and satisfactory and was finally adopted.

Before each test the subject was given as much time as he wished for practice. He did not know exactly when his test-period began nor when it was likely to close—except that he knew that it would not extend over twenty minutes. By this method the factors of "warming up," of the nervousness frequently attendant on beginning a piece of work, and of the "final spurt" were almost entirely eliminated. The actual test-period was made fifteen minutes long in all cases, although none of the subjects knew this fact—fifteen minutes being the length of time determined upon as sufficient *to indicate many of the characteristics of fatigue, to show the tendency of these characteristics, and to bring out important points regarding the nature of muscular inaccuracies.* The tests were made on successive days and

at the same hour each day for the given subject as far as possible; any variations were noted. A record of the subject's general physical condition at the beginning of each test was kept and also of the subject's introspections at the close of the daily trial.

The following method of evaluation of errors was adopted as being the most satisfactory. If the block was misplaced to the left, for example, so as to establish the connection represented by the termini *aa'* (illustrated by the dotted square *r*, Fig. 2), one error was counted; if, as shown by the dotted square *r'*, the block was misplaced so as to make the connections *bb'* and *dd'*, two errors were recorded. If either hand of the subject was hit by the revolving shields *s* and *s'*, three errors were counted—such an occurrence being a gross inaccuracy. Failure to put in a block—being the omission of a whole muscular co-ordination—was evaluated at five errors. Other types of maladjustments occurred occasionally and were evaluated on the above basis.

It may be well to note that in these experiments an essential feature of the method is that stimuli were provided of the so-called extrinsic nature.[4] The machine being driven by electricity set the pace and the subject was required to keep up. To the observer these tests appeared as a real contest between human muscle and sensitive nerves, and the machine, insensible and indefatigable. The machine regularly worked on and on; the subject worked irregularly, with increasing tendency to fall behind.

Although in these experiments no saws, knives, or drills were present and hence gross muscular inaccuracies did not mean actual mutilation of the subject's hands, this fact appeared to be adequately balanced by three other factors. (*a*) Throughout the experiments each subject clearly manifested an instinctive dread of getting hit by the revolving shield—even in the final experiments, the subject would instinctively jerk back his hand whenever he became conscious that his hand was likely to be hit. (*b*) Throughout the experiments the records of each subject were posted and a healthy spirit of competition was maintained which assisted greatly in keeping up a maximum efficiency. (*c*) In particular, the graduated system of evaluating inaccurate co-ordinations served continually in keeping down the number of

[4] W. H. R. Rivers, *The Influence of Alcohol, etc., on Fatigue*, 12.

gross inaccuracies. The writer believes that these factors when taken together served to maintain a degree of carefulness in operating this experimental machine comparable to that manifested by the average worker in the dangerous trades, who inevitably becomes inured to the danger of working close to revolving knives, saws, drills, etc.

Eleven subjects participated in these experiments.[5] Br., Hy., Pr., Sp., Sw., and Wr. were men; Ch., Fr., Hys., My., and Wd. were women. This list included trained psychologists who had worked at reaction-time experiments, at co-ordination of hand and eye movements, at general fatigue experiments. Three of the subjects had taken part in the prolonged series of fatigue experiments conducted by Yoakum. One of the subjects had worked in a screw room; another, as an operator in a telephone exchange. In view of the considerable amount of practice which was given in these experiments the results did not show any particular effects of the previous training of the subjects. This point will be discussed later. Further details regarding methods will be given when the various groups of experiments are described.

The first group of experiments was designed to get a maximum of simplicity of operation, of monotony, of speed, and of mental strain or unrelaxed tension. The rate was such as to require that a block be set on the square x (Figs. 1 and 2) once a second or sixty times per minute. Two blocks were used. The cycle of a single operation may be described as follows: (*a*) stopping block 1 with the left hand when brushed off the square x by the machine, and putting block 2 on the square x with the right hand; (*b*) passing block 1 over from the left hand to the right hand; (*c*) placing block 1 on the square with the right hand while the left hand stopped block 2; and so on. The monotony, speed, and unrelaxed tension of this process is obvious.

Eight subjects—four men, Hy., Pr., Sp., Sw., and four women, Ch., Fr., Hys., and Wd.—worked in Group I. Each subject was given several practice trials, covering two or three weeks, until the maximum efficiency was obtained, as far as could

[5] The writer wishes to express his deep obligation to the persons who willingly gave of their time and strength that this investigation might be furthered.

be judged by the daily records of errors. The tests were then continued until six to ten normal records were obtained for each subject. By the use of volitional power and highly concentrated attention, and as a result of a strong spirit of rivalry, the subject tried in each test to make no errors or to keep the errors within minimum limits.

Among other things, the errors of each subject were tabulated according to their occurrence in the first or in the second half of the given test periods.[6] The tabulated figures for each subject were added together and the average daily number of errors for the first and second halves of the test periods was obtained. The results appear in Table II.

TABLE II

MUSCULAR INACCURACIES (GROUP I)

Subject	Average Number of Errors, First Half	Average Number of Errors, Second Half	Average Total Number of Errors
Ch.	3.00	6.00	9.00
Fr.	6.16	15.83	21.99
Hy.	6.66	12.00	18.66
Hys.	5.16	13.00	18.16
Pr.	2.00	5.83	7.83
Sp.	4.50	5.83	10.33
Sw.	1.83	4.00	5.83
Wd.	1.66	3.83	5.49
Total	30.97	66.32	97.29
General average	3.87	8.29	12.16

From Table II it will be observed that the average daily number of errors for all subjects was 3.87 for the first half of the test periods and 8.29 for the second half. In other words, 31.82 per cent of the errors occurred in the first half of the test periods and 68.17 per cent in the last half. As determined by the introspections, the immediate cause of the distribution of muscular inaccuracies in this fashion is to be found largely in the irregularly decreasing effectiveness of the attentive processes. In par-

[6] In analyzing the results of these experiments, a large number of tables have been made. Only those have been selected for use here which best present the general results. It is difficult to avoid the omission of some classifications of data which might prove helpful.

ticular, such factors entered as rise of feelings of effort, of strains, of fatigue in the muscles of the eyes, arms, back, hands, legs, abdomen, etc. In many of the tests the subjects experienced a growing uncertainty of muscular control over the hands.

Whatever the cause, the most significant result of this group of experiments was the fact that the subjects were not able to maintain a steady degree of volitional attention even though they knew that the test would cover a short period of not over twenty minutes. During these tests the subjective processes broke down, in spite of continued efforts of the subjects to the contrary, to the extent of permitting practically twice as many errors to occur in the second half as in the first half of the work period. Some of the subjects, whose work in this group of experiments is fairly typical, are working for much longer test periods. The strain on the individual caused by the greater length of the work period is compensated by giving him a slower rate of speed. While full results are not yet at hand, the indications are that when the longer period is divided into two equal periods for purposes of comparisons, the relation between the number of errors occurring during the first half and during the second half of such a period is almost a duplicate of the results shown in Table II. In other words, when the operation of the experimental machine is made less rigorous and continued for greater lengths of time, so that fatigue does not develop in fifteen minutes (as in the experiments already described), but in the given increased period of time, it may be assumed that the results in Table II would not suffer material change.

Tables II and III illustrate the law of fatigue as given at the close of Section II, that continued work is accompanied by increasing muscular inaccuracy. Granted that the general results of this group of experiments would not have been essentially changed if a lower rate of speed had been substituted for a high rate and a longer period of time substituted for a short period—two substitutions which may be considered as counterbalancing each other in a large measure—then the following conclusion may be given: If the subjects in this series of experiments had been operating dangerous machines where slight misplacements

mean mutilation, *the danger of accidents would have been far greater* (if not twice as great) *in the latter half than in the first half of a given work period.*

In Section II the point was emphasized that the increase in muscular inaccuracy which accompanies continued work depends on the rate of work. That is to say, if the operative of a dangerous machine should be "speeded up," his danger of suffering accident would be thereby increased; and that increased danger would persist as long as the increase in rate of work remained a "speeded-up" operation for the given operative. According to the law given at the close of Section II, an increase in speed will hasten the fatigue processes, the development of muscular inaccuracies, and hence the chances of accident.

In testing this point the apparatus used in the preceding series was slightly modified. A pipe *p* and a square box *q* containing a dozen inch cubes were added to the apparatus (see Fig. 1). By this time the observation method had been so satisfactorily developed that the brass plates on one side of the blocks were taken off and the subject permitted to place the blocks with any side down. The cycle of operations consisted in catching the block with the left hand as it was brushed off the square *x* by the machine and of dropping it in the opening of the spout *p*. In the mean time the right hand had to pick out another of the blocks from box *q* and place it accurately on the square *x*.

The speed was made one-half that of the preceding series, or 30 blocks per minute. This was a rate which seemed slow or moderate to most of the subjects and errors appeared to occur more as a result of chance than from any other cause. As far as the speed was concerned, there was no excuse for errors. Tests were made daily at this rate until a series of records was secured sufficient to serve as a basis of comparison with the results obtained from speeding up. Then the rate was increased from 30 to 37½ blocks per minute. On the day that test 1 was made at the faster rate, and preceding the test, the subject was given all the time that he wished for practice. Tests at the 37½ rate were continued for twelve days for all subjects. Then a faster rate of 45 blocks per minute was offered. Table III gives

the number of errors made by each subject during the series of trials at the three rates of speed.

TABLE III

Muscular Inaccuracies (Group II)

Rate	No. of Trials	Br.	Fr.	Hy.	Hys.	My.	Pr.	Wd.	Wr.	Total
30......	1	1	2	2	4	4	0	6	16	35
	2	1	6	8	2	5	1	0	4	27
	3	2	3	0	0	0	12	6	9	32
	4	0	1	6	1	3	2	1	1	15
37½.....	1	25	92	39	127	14	39	2	44	387
	2	17	57	15	31	10	54	3	23	212
	3	21	15	13	18	16	15	7	39	144
	4	10	5	29	61	14	7	3	38	167
	5	9	6	18	5	10	44	3	26	117
	6	9	23	3	20	11	23	1	18	118
	7	4	12	4	1	2	7	7	14	51
	8	3	29	2	4	7	17	3	6	81
	9	3	23	1	31	4	34	1	6	103
	10	3	1	7	6	1	2	6	7	33
	11	3	22	22	4	0	8	7	4	70
	12	0	9	7	7	0	7	7	33	70
45......	1	48	128	52	148	65	115	70	325	943
	2	101	108	18	166	56	134	56	88	736
	3	123	117	32	75	34	104	64	202	751
	4	57	182	75	21	13	102	26	108	584
	5	46	79	82	134	15	118	16	256	746

Although the first trials at the 37½ rate in the case of each subject were preceded by a practice period, the effect of speeding up from a 30 to a 37½ rate on muscular inaccuracy is marked. As indicated by Table III, the increase varies considerably from the case of Wd. to that of Hys., where the increase in number of inaccuracies is from 1 to 127. For the first six trials at the 37½ rate the process was clearly a speeded-up one for all the subjects excepting Wd.; a decrease in errors is also characteristic. For the last six trials at the 37½ rate, the totals of errors indicate that no further decrease in inaccuracies would have resulted if the series at this rate had been continued. The introspections given by the subjects bear out this conclusion. The totals for these last six trials also indicate that the 37½ rate had become a much less speeded-up process than for the first six trials at

that rate, but that it still remained a speeded-up process when compared with the records for the 30 rate.

Table III shows that the introduction of the 45 rate (although the first trials were again preceded by a practice period) was accompanied by a large increase in the number of errors. Table IV is prepared from Table III and indicates the relative percentage of errors occurring in the first and second half of the trials at the 30 rate, for the first six and for the second six trials at the 37½ rate, and for the 45 rate, for each subject; at the 30 or slow rate where errors were not due to speed, but apparently to chance, the average percentages of errors indicate that practically the same number of inaccuracies occurred in the first half as in the second half of the given work period—the ratio being 50.0 to 49.8.

But when the rate was increased to 37½ blocks per minute there occurred not only a large increase in the actual number of errors, but, as will be seen by looking at Table IV, a large proportion of the inaccuracies occurred in the second half of the given trials. The ratio of errors between the first and second halves of the first six trials at the 37½ rate was 33.4 to 66.5. For the second six trials at the 37½ rate when this rate no longer involved as speeded-up operations as during the first six tests, because of skill resulting from practice, the percentage of inac-

TABLE IV

PERCENTAGE OF ERRORS (FROM TABLE III)

Subject	30 Rate		37½ Rate (First Six Trials)		37½ Rate (Second Six Trials)		45 Rate	
	First Half	Second Half	First Half	Second Half	First Half	Second Half	First Half	Second Half
Br	75.0	25.0	49.4	50.5	43.7	56.2	33.6	66.3
Fr	33.3	66.6	49.4	62.8	32.0	67.8	29.9	70.0
Hy	50.0	50.0	37.6	62.3	60.4	39.5	38.4	61.5
Hys	25.0	75.0	42.3	57.6	39.6	60.3	36.7	63.2
My	66.6	33.3	24.0	76.0	35.7	64.2	44.5	55.4
Pr	73.3	26.6	19.1	80.8	41.3	58.6	34.8	65.1
Wd	30.7	69.2	26.3	73.6	29.0	70.9	26.9	73.0
Wr	46.6	53.3	31.5	68.4	50.7	49.2	40.9	59.0
Average	50.0	49.8	33.4	66.5	41.5	58.3	35.7	64.2

curacies fell, the ratio being 41.5 to 58.8. When the rate was increased to 45 blocks per minute, the process again became a speeded-up one and the percentage of inaccuracies in the last half of the trial periods again rose—this time to 64.2 per cent. The ratio was 35.7 to 64.2.

The noteworthy fact in these experiments is that as soon as the work was speeded up from the 30 to the 37½ rate or from the 37½ to the 45 rate, the larger part of the increase of errors took place in the latter half of the given work periods. These increases clearly show the effect of fatigue on muscular inaccuracies. This conclusion, based on the objective records, is corroborated by the introspections given by the subjects. While operating the machine at the speeded-up rates, all the subjects complained of sensations of fatigue during the second half of the work periods, ranging from distinct strains in the muscles of the eyes, arms, and hands to temporary paralysis of the right arm (Wr., in whose case the right arm co-ordinations broke down completely, and the subject was forced to *stop in one test*). Typical introspective reports are subjoined:

Eye strain felt during last three or four minutes.

Slammed blocks in toward close of period, because of less certainty of muscle control.

During last half of period eyes blurred continually.

Back began to ache about middle of period and continued.

Conscious of increasing inaccuracy and of increasing feeling of "losing out."

Greater tendency toward the last to fumble blocks.

Fumbling increased, caused by developing fatigue in fore-arm, and by lapses of attention.

Fatigue in arms felt early in trial.

Fagged all over—to keep up the process became a torture.

Felt pain between shoulders toward the last.

Almost decided that I couldn't keep it up for full period.

Compelled to exert increasing volitional power.

Strain in left arm toward the end of the period.

Increasingly tended to get behind in muscular movements.

Boredom of it increased.

Last few minutes seemed like hours.

Started well, but fatigue developed in arms, wrists, shoulders.

Terrible strain developed in right arm.

Became aware of a general inaccurate feeling in regard to hands.

One or two other points brought out by this group of experiments may be mentioned here. Reference to the tables will make clear the fact of marked individual difference in regard to making errors. These variations do not appear to be explained when the subjects are classified on the men and women basis or according to the degree of psychological training, but rather by temperamental differences. Reference to the records of individual subjects (Table III) shows marked variations from day to day in many cases. The explanation for this fact appears to be found in the varying bodily conditions of the given subject from day to day. The decidedly abnormal conditions were of two kinds—either the subject found himself simply "out of form," or else he began the test normally and errors began to increase early and rapidly as a result of late hours, overwork, forms of illness.

The material presented in this section may be summarized at this point. These experiments indicate that *uninterrupted work is accompanied by increasing muscular inaccuracy, and other things being equal, any speeding up in the operation of dangerous machinery means accelerated development of fatigue and of muscular inaccuracy.* In other words, fatigue causes muscular inaccuracy. Since, as indicated in Section III of this study, men and women in the hazardous employments are working in close proximity to dangerous tools, and where misplacement of the hands a fraction of an inch means mutilation, the material presented in this section may be considered as evidence that fatigue causes accidents. The data presented in Section III to the effect that muscular inaccuracies are the actual phenomena preceding a large majority of accidents bears out the conclusion that fatigue, muscular inaccuracies, and industrial accidents are causally related. In the next section, the hours when accidents occur will be analyzed.

[*To be concluded*]